Cognitive Security and Resilience: A Social Ecological Model of Disinformation and other Harms with Applications to COVID-19 Vaccine Information Behaviors

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Abstract

Access to and discovery of credible information is the product of numerous, interacting factors including individual characteristics and behaviors as well as features of the information environment, social, cultural, and institutional norms, policies and regulations, and more. To date, most research on information disorder has focused either on the individual or on the information environment (or on the technology that allows an individual to access the information environment), but there is a lack of systematic, theory-driven research on the dynamic relationship between the individual and their environment. In this study, we propose a novel application of Brofenbrenner's social ecological model to the study of cognitive security and resilience in the context of information disorder. First, we describe the refitting of the model from public health and human development to cognitive security. Using extant literature in the field, we identify the key factors at each level of influence — including individual-level factors such as attitudes/beliefs, knowledge/experience, and demographic characteristics, as well as higher-level factors at the interpersonal-, organizational/institutional-, community-, and policy/culture-levels — that shape susceptibility and resilience to information disorder. We also consider the dynamic interactions between individuals, groups, societies, and characteristics of the technological environment, including how algorithms and artificial intelligence interact with individual behaviors, policies, and organizational decision-making to shape access to and discoverability of credible information. Finally, we describe an application of the model to a use case involving COVID-19-related information behaviors. To our knowledge, this is the first time Brofenbrenner's social ecological model has been applied in full as a conceptual foundation for the study of cognitive security and resilience. Our findings provide important new insight into the social, cultural, and structural factors that shape information behaviors and access to credible information, as well as the impact of information disorder. The results can be used to identify vulnerabilities and targets for future information-related initiatives and interventions (such as fact-checking and journalism initiatives) and to inform evaluations of such initiatives, as well as to better understand variation in susceptibility and resilience to information disorder. Further, this study lays an important conceptual foundation for future research to expand on this use case and refine the application of the social ecological model to the information domain.

Keywords

cognitive security, social ecological model, misinformation, information disorder, information behavior, COVID-19

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1. Introduction

The United States of America (US) presidential elections in 2016 and 2020, the Brexit referendum in 2016, and now the ongoing coronavirus pandemic, have thrust the issue of information disorder into the global spotlight, leading to greater awareness of the challenge and a surge of new efforts to address it. First conceptualized by Wardle and Derakhshan, information disorder describes the creation and/or sharing of false or misleading information, whether deliberately or unwittingly, with or without the intent to cause harm [1]. The concept encompasses misinformation — that is, the unintentional sharing of false information — as well as disinformation, or information that is deliberately false or misleading [2]. It also includes a third category of misleading content, malinformation, which describes genuine information that is shared with the intent to cause harm.

Although the spread of false and misleading content is not a new phenomenon, the internet, and particularly social media, have given rise to a fundamental change in how people communicate and how information is disseminated and accessed, which has contributed to the viral spread of mis- and disinformation as well as targeted propaganda and influence campaigns. The "three Vs" of volume, velocity, and variety from big data also contribute to the reach of disinformation, cognitive overloads in processing it, and in the ability of disinformation creators to rapidly test and adjust messaging, channels and media to maximize impact. The scale of the problem and its far-reaching effects have created an urgent need to develop effective strategies to counter information disorder and facilitate better access to and engagement with credible information, but these efforts have been hampered by fundamental challenges including inconsistent terminology, a lack of integration of research from different disciplines, and underuse of theory. To more effectively address the challenges posed by information disorder, it is first necessary to develop a better understanding of the problem and identify the most promising avenues to counter it.

The causes of and contributors to information disorder are complex and multifaceted, and the existing literature on information disorder spans numerous fields including communication, media studies, public health, psychology, computer and information science, and security studies. Studies have examined the characteristics that make individuals susceptible to information disorder, as well as the characteristics of the information itself, the networks in which it spreads, and the platforms and technologies that enable individuals to form networks and engage with information. However, there is a lack of foundational, theory-based research examining how these agents, processes, and environments interact with each other and respond to change.

In this paper, we propose a novel framework for conceptualizing cognitive security and resilience in the context of information disorder and information-based harms. We take a sociotechnical systems view of mis- and disinformation, drawing from information security tools and processes, as well as cognitive security's twin definitions of adversarial machine learning that affects machine beliefs, and social engineering at large scale, which we term adversarial cognition [3, 4]. In this paper, we define cognitive security as the ability to detect, characterize, and counter misinformation, disinformation, and other information-based harms and forms of malign influence among people. Resilience, as part of cognitive security, includes the structural context that protects humans from exposure to disinformation in the first place, as well as the ability to identify it, limit its spread, and mitigate its effects once exposed. Throughout this

paper, we use the term “information-based harms” to refer to misinformation, disinformation, conspiracy theories, and a variety of other types of potentially harmful information.

The framework we are proposing builds on existing work that has applied fundamental concepts from the field of public health to the study of information and information disorder. For example, the spread of rumors and other falsehoods on social media is often compared to the spread of contagious viruses, which is why widely-shared posts are said to have “gone viral.” However, there are limits to this epidemiology-based model; discussing rumors and misinformation as malicious viruses to be contained and removed creates stigma on participants in them, especially where they arise from genuine information behaviors and social interaction. There are parallels here to the first applications of the Social Ecological Model and other ecological frameworks in the field of the public health, which came in response to criticism that traditional approaches to studying health and disease — which largely focused on individual characteristics and behaviors — promoted a victim-blaming mentality in which blame for poor health outcomes was placed on the shoulders of individuals, often without consideration of the structural and environmental causes.

Our proposed model is an adaptation of Broffenbrenner’s Social Ecological Model (SEM), which was initially developed as a framework through which to understand human development, with a particular emphasis on the dynamic interactions between individuals and their environments [5]. Since its inception in the 1970s, the SEM has been applied in various formats across a variety of domains including public health [6], health literacy [7], media and communications [8], risk management [9], and organizational change [10]. The model recognizes individuals as embedded within multiple levels of interacting systems, and within each of these systems there are myriad factors that directly and indirectly influence the individual and are influenced by the individual. This core assumption — that individuals can influence their environment and that the environment can influence the individual — is known as reciprocal causation.

Where and how you retrieve information matters: information seekers not only analyze retrieved information, they also co-create the information search terms that they use with different levels of their personal SEMs, leading to term-based information silos [11]. The credibility of retrieved information is based on factors that include, according to Self as quoted by Pasi, "(i) the source of information, (ii) the information that is diffused, i.e., the message, considering both its structure and its content, and (iii) the media used to diffuse information" [12], [13]. The Admiralty Code [14] is widely used to assess credibility in information retrieval and open source intelligence (OSINT) by separately rating information contents and sources, but there is scant research on the effects of the type of source, and their relationship to the information seeker, or on the credibility they assign to information retrieved through personal communication, online search, networking, and OSINT. This SEM extends information retrieval to give ways to consider the source and the effects of source assessment on retrieved information credibility.

While the levels of the SEM have been conceptualized and labeled in different ways over the course of the past five decades, this study builds on a version of the model that is widely used in public health, health promotion, and behavior change research. This framework, an adaptation of Brofenbrenner’s model put forth by McLeroy and colleagues, specifies five levels of influence that interact with each other and with the individual, starting with the individual level, which encompasses the most proximal layer of influences such as demographic factors,

identity, political ideology, attitudes, beliefs, emotions, knowledge/skills, behaviors, and more [15]. The second level of the model, the interpersonal level, comprises the external social influences of family, friends, and other close relationships, as well as related social factors such as group norms and social support. The organizational level of influence describes the organizations and institutions in which social relationships occur and in which policies and regulations originate. In the public health context, this would include local, state, federal, and global health agencies such as the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO). The next level of influence is the community level, which focuses on the networks that connect organizations and institutions, the settings in which they exist, and the culture and norms that emanate from these spaces. Examples include the public health community, the global aid community, the information security community, and the education community. The fifth level is the policy/societal level, which includes broad societal factors that create a climate in which certain practices, behaviors, and phenomena are either reinforced/encouraged or inhibited/discouraged, as well as factors such as poverty, inequality, discrimination and bias, and strength of democracy. This level also includes the policies that create or reduce poverty, inequality, discrimination, and related factors, as well as policies focused on technology, information, security, and defense. For the purposes of this study, we chose to describe these layers separately, as we identified several key areas where policy and society were moving at different speeds, and/or where coalitions involved in policy-making spanned numerous, heterogeneous societies and thus were not accurately captured in a single level.

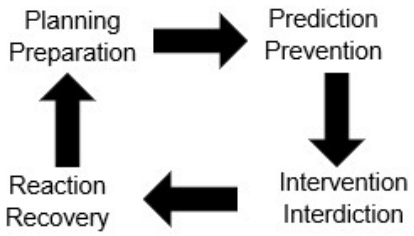

Figure 1: Emergency Cycle Crisis Stages

Throughout this paper, we also consider different stages of cognitive security. These include planning and preparation of responses, prediction and prevention, intervention and interdiction, reaction and recovery. Planning builds connections to responders across the SEM model, and creates a "muscle memory" for later responses. Prediction works to identify potential and emerging cognitive security incidents, Intervention responds to incidents, and reduces the capability of incident components to do damage (e.g. by rate-limiting botnets). Recovery is damage repair after an incident, including evaluating incident responses and learning from these. Issues with stages include that responders often find themselves in multiple stages at the same time, and that there are observe–orient–decide–act (OODA) loop-style feedback loops in these cycles. Figure 1 illustrates this.

2. Related Work

The SEM has been used as a framework for research and program planning in a variety of fields, particularly within the areas of human development, public health, and intervention planning. In recent years, increasing attention has been given to ecological models like the SEM, in large part because federal agencies like the National Institutes of Health (NIH) Office

of Behavioral and Social Science Research (OBSSR) and the CDC have issued calls for more research incorporating transdisciplinary science and systems science methods in an effort to better understand the multilevel influences on health and disease [16]. Although there are many parallels between the study of information disorder and the fields of public health and behavioral science, there are few applications of the SEM and related models in the area of information-based harms.

Lewin was among the first scientists to adopt an ecological approach to understanding human behavior [17]. Brofenbrenner, a student of Lewin, is credited with formulating ecological systems theory, which views individuals as agents who influence, and are influenced by, their environments [5]. The SEM, which is rooted in ecological systems theory, also incorporates principles from systems science, including Watzlawick, Weakland, and Fisch's theory of problem formation and problem resolution, which provides a framework for understanding why certain problems persist while others are resolved [18]. Watzlawick's theory is based on the idea that there are at least two distinct types of change: first-order change and second-order change. First-order change occurs when a change is made inside a system, or a particular symptom or need is addressed, but the system itself (and its processes and structures) remains unchanged. Second-order change, on the other hand, occurs when a modification is made to the system itself, such as when a process or structure is added or removed from the system.

Expanding on this line of work, Glass and McAtee developed a multilevel model of human behavior to advance the study of behavioral science within the context of public health [19]. At the time, the public health community was struggling to develop more effective approaches to reduce behavioral risk factors such as smoking and physical inactivity. Historically, behavioral science had approached these problems by focusing on individual characteristics and behaviors, but by the 1990's it was becoming increasingly clear that there was a pressing need to better understand the social context in which these behaviors are shaped. In response to calls from leading public health scholars to advance a new research agenda focusing on the social causes and context of disease [20, 21, 22], Glass and McAtee proposed an integrated approach to studying health behavior that recognized that nearly all public health problems have multiple causes and are shaped by multiple factors at different levels of influence, and that behavioral health is the product of both social-environmental and biological processes and systems [19].

In the fields of public health and behavioral science, there is strong evidence that interventions are more likely to be effective if they are based on ecological models like the SEM, rather than individual-level theories, because of the SEM's focus on multicausality and multilevel influences on health and behavior [23]. As such, the SEM has been applied in numerous ways to a variety of health conditions, behaviors, and public health problems, ranging from intimate partner violence[24] and firearm injuries [25], to obesity [26] and cancer screening [27], to bullying [28] and suicide prevention [29]. The SEM has also been used during the COVID-19 pandemic as a framework to study the determinants of preventive behaviors related to the virus, including vaccine intentions [30] and mask use [31], to understand vulnerability and resilience among elderly populations [32], to explain country-level variation in COVID-19 abatement efforts [33], and to conceptualize the impact of the pandemic on other health issues such as opiate use [34].

McCormack and colleagues applied the SEM to the study of health literacy and patient engagement, showing how both concepts are influenced by social and contextual factors such as the delivery of health-related information, the communication skills of public health professionals

and medical providers, the characteristics of public health institutions, and the policies that affect health-related organizations, providers, and patients [35]. After identifying the factors at each level that influence health literacy and patient engagement, the authors incorporated ecological processes such as pooled interdependence — a term that describes the cumulative impact of intervention effects — to specify intervention strategies that could be used to target factors at each level of the model.

The SEM and other ecological models have also been applied to the study of infectious disease outbreaks [36] and emerging infectious diseases [37] to understand the dynamic interactions between pathogens, hosts, individuals, and their environments, and how changes to any one of these can influence the spread of disease, the susceptibility of populations and subgroups, the severity of disease outcomes, and more. In this context, ecological models have primarily been used for the purposes of risk and needs assessment, identifying priorities for intervention, and evaluating the impact of prevention and treatment strategies.

Additionally, the SEM was used by members of an international coalition funded by the United States Agency for International Development (USAID) to identify ideal communication strategies to promote health behavior change in response to the 2014 Ebola epidemic, during which fear, mistrust, and miscommunication severely hampered outbreak response efforts [38]. Although the Ebola epidemic differs from the coronavirus pandemic in many key aspects, there are also many parallels between the two situations — namely, the challenge of effective communication in the face of an unprecedented crisis, widespread mistrust eroding public health efforts, and a rapidly evolving, emotionally-charged situation that left the population vulnerable to rumors and misinformation — that make the Ebola epidemic an important example from which we can learn key lessons to apply in the present. Initial communication efforts during the Ebola outbreak were largely focused on psychosocial determinants of behavior change, however as the authors noted, it soon "became evident that controlling the epidemic required communication interventions to address levels higher than the individual, namely, community and normative level factors that could influence the desired behaviors, service-level factors that provided critical resources for the ill, and policy-level factors to guide a coordinated response within a very limited timeframe" [38]. As such, members of the USAID-sponsored Health Communication Capacity Collaborative (HC3) project turned to the SEM to formulate a more comprehensive strategy that explicitly identified possible causal mechanisms to promote behavior change through domain-based communication activities focused on community dialogue, social change, service delivery, and individual and household factors.

Most recently, during the coronavirus pandemic, the SEM has been used to guide the exploration of COVID-19 vaccine intentions and identify subgroups with negative vaccine intentions, who may represent ideal targets for intervention [30]. The study used survey data and broke down the items into the levels of the SEM, then used univariate and multivariate models to compare participants who intended to get vaccinated against COVID-19 to respondents who did not intend to get vaccinated or who were ambivalent about getting vaccinated. The results pointed to several potential factors to target in vaccine promotion campaigns, including gender (males were significantly more likely to have negative intentions to get vaccinated), race (participants who identified as Black were significantly more likely to have negative intentions to get vaccinated), conservative political ideology, and social norms (participants whose peers did not engage in or support COVID-19 prevention behaviors were significantly more likely to have

negative intentions). This builds on previous research using the SEM and related ecological models to investigate vaccine attitudes, including Walker and colleagues' qualitative study of confusion, mistrust, and hesitancy among mothers who had accepted the HPV vaccine for their children but were not confident in their decision [39]. This is an important subgroup for several reasons. First, many vaccinations require multiple doses to be effective, so ongoing hesitancy after initial acceptance can be a barrier to completing a full vaccination series. Secondly, although individuals may choose to accept one vaccine and reject others (or vice versa), there is a risk that hesitancy about one vaccine could develop into more generalized vaccine hesitancy. For these reasons, individuals who have accepted a vaccine but remain hesitant are still a key group to consider in vaccine communication and promotion activities. In the study of HPV vaccine-accepting mothers, interview data revealed that media and social media were key sources of mistrust and confusion, and that although most mothers indicated a high degree of trust in their children's health care providers, the information they got from providers was often undermined by information they got from other sources, such as friends, family, and the media. The authors suggested that, in light of parents' increased access to and engagement with credible and noncredible sources of information online, and the subsequent expectation to be more involved in health decision-making, traditional models of the patient-provider relationship and communication may need to be revised [39].

Much like the field of public health at the turn of the century, we now find ourselves facing a complex challenge that threatens the health of both individuals and societies, but which has been resistant to most efforts to promote change. To date, the vast majority of research on information-related harms has focused either on individual characteristics and behaviors — such as why certain people are more susceptible to mis- and disinformation — or on the platforms and technologies that facilitate the spread of the problem. Other research has approached this problem by exploring characteristics of information itself, such as why certain misleading content is more likely to go viral. However, there is a lack of theory-based research that integrates these different approaches and explicitly considers the interactions between individuals, information, and the technologies and environments that enable individuals to encounter and engage with information. We hope to help fill that gap with our proposal for a novel application of the SEM to the study of cognitive security.

3. Social Ecological Model of Cognitive Security

Figure 2 offers a graphical representation of the SEM for cognitive security with factors discussed in the sections below.

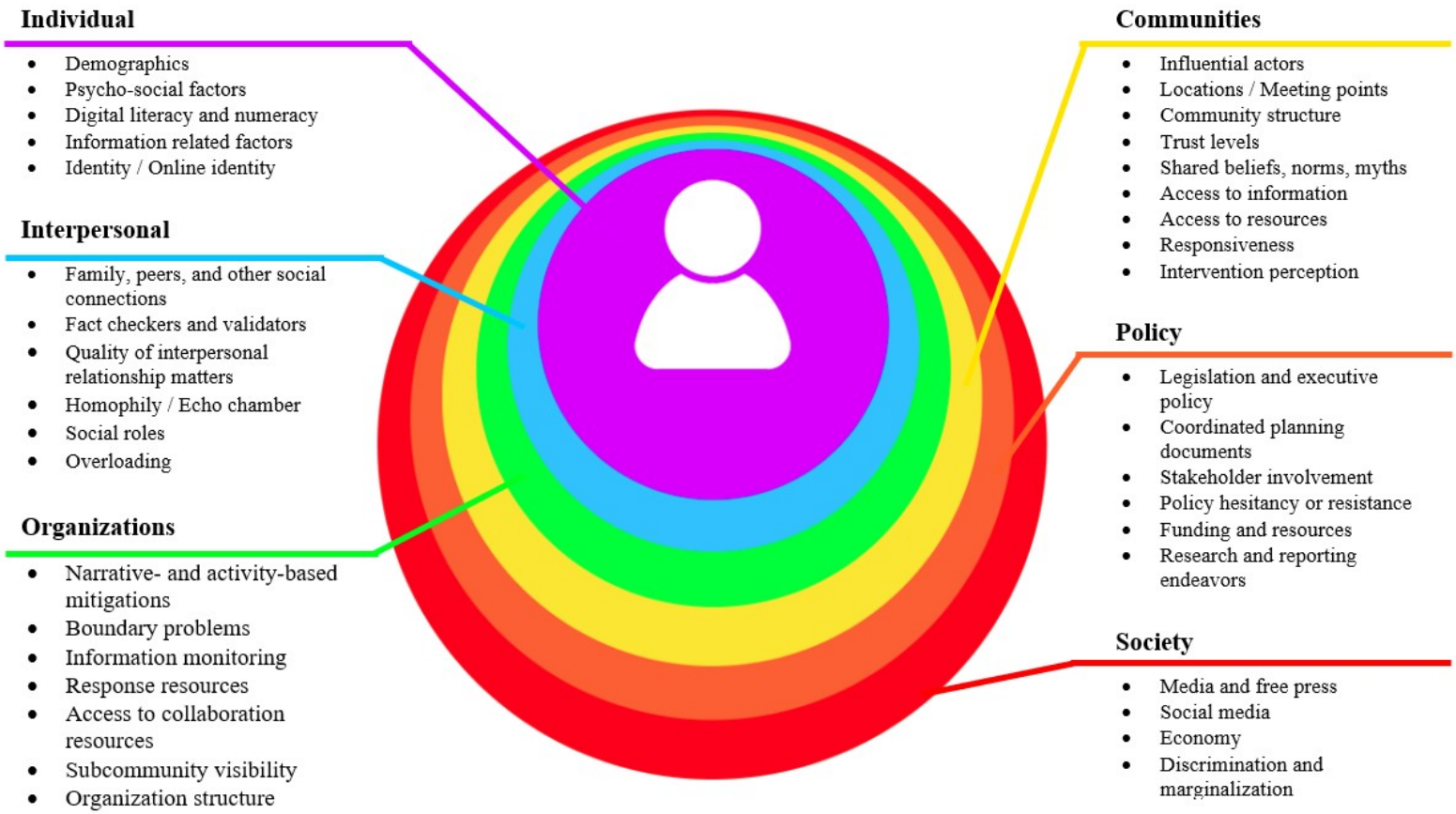

Figure 2: Social Ecological Model for Cognitive Security and Resilience

3.1. Individual

Individual-level determinants of cognitive security and resilience encompass a wide variety of characteristics including demographic and psychosocial factors, ideology, knowledge and technical skills, digital literacy and digital numeracy, as well as information needs, information evaluation, and information behaviors. These factors interact with each other and with the information environment, creating a dynamic situation in which characteristics of the individual influence their information needs, evaluation, and behavior, which in turn influences the types of information they seek, attend to, share, and recall.

Demographics: Cognitive security and resilience are influenced by a variety of demographic factors, including age, race, gender, socioeconomic status, language and vocabulary. For example, older individuals (over the age of 65) have been found to be more vulnerable to false information disseminated via social media and messaging apps [40, 41]. Among youth, social and cognitive development are important determinants of cognitive security and resilience due to their influence on information evaluation and uptake. For example, younger children struggle with certain website design features such as content lists and maps, but benefit more than older children from learning cues such as pop-ups explaining the main point of a webpage [42]. Although children generally struggle more than adults with tasks that require analytical thinking and complex judgments, youth tend to be more comfortable using new technologies and are often more motivated to engage with emerging technologies [42]. Other research has found enduring racial, socioeconomic, and age-based divides in access to and use of communication technologies [43, 44, 41]. Certain dynamics of religiosity, including fundamentalism and dogmatism, have been found to be associated with reduced analytical thinking and, subsequently, greater susceptibility to conspiracy theories and other falsehoods [45]. Political ideology has also been shown to influence susceptibility to misinformation, such that individuals who identify as conservative appear to be more susceptible to political misinformation than left-leaning or ideologically neutral individuals [46]. Language and vocabulary are also important determinants of cognitive security and vulnerability. These factors can interact with the technological and information environments, leading to challenges such as the "vocabulary mismatch problem," which describes a phenomenon in which different people and/or systems use different labels to describe the same concept. Put differently, vocabulary mismatch occurs when "the way users express concepts differs from the way they appear in the corpus" [47] or when the terms between queries and documents are lexically different but semantically similar [48].

Psychosocial factors: Cognitive security and resilience are also influenced by a variety of psychosocial determinants, including attitudes and beliefs about technology and about the topic at hand, trust in information and sources of information, as well as the technology used to access it, subjective norms surrounding source credibility and information-sharing, cognitive biases, risk perceptions, stress, trauma, emotional state and emotional reactivity, and more [49, 50].

Digital literacy and numeracy: Technical knowledge and skills, as well as subject-specific knowledge and familiarity with the topic at hand, are also important determinants of cognitive security and resilience. In particular, digital literacy, which the Department of Education defines as "the skills associated with using technology to enable users to find, evaluate, organize, create,

and communicate information," [51] and digital numeracy, which involves the ability to process basic numeric concepts and is closely tied to decision-making ability, have been shown to be associated with susceptibility to misinformation, such that individuals with low digital numeracy tend to be more likely to believe misinformation they encounter online [52]. In one recent study on coronavirus-related misinformation, digital numeracy was found to be the strongest predictor of susceptibility to misinformation [49].

Information-related factors: Other individual-level determinants of cognitive security and resilience include information needs and how they are expressed (e.g., how people interact with search engines), evaluation of information and sources (e.g., relevance and credibility judgments), perceived usefulness (of the information), time spent with the information, and a variety of information behaviors including search behaviors and information seeking, information sharing, and engaging with information.

3.2. Interpersonal

At the relationships layer, influence on an individual's cognitive security depends upon the viewpoints of family, peers, and other social connections. The social environment enables individuals to affect how others receive, perceive, and understand information, as well as be affected by others. Likewise, social norms link individuals and through interpersonal relationships within the social environment, contributing toward cognitive security development within the group. Similar protective information sharing occurs through prosocial gossip as a way to defend members of the social group [53] and between the social strata of leadership [54, 55].

Families and peers: Families and peers are the first connections in the social environment. This group serves as a natural support system, signal for belonging, and potential source of and filter for credible information. They serve as fact-checkers and validators to increase individual cognitive security [56]. Yet, individual attributes of family members and peers, as well as group demographics, mediate credibility [41]. Additionally, family and peers as sources of credibility information and attitude change agents is further mediated by individual cognitive ability [57].

Relationship quality: In addition to the presence of this social connection, the quality of that interpersonal relationship matters. Where an individual may initially recognize and dismiss instances of disinformation, they are more likely to become involved when family and peers consume or are affected by that disinformation [58]. Attempts to correct incorrect information, an outward cognitive security exercise, could be interpreted as quarrelsome behavior. Therefore, it is more likely to occur among family and peers, where the relationship could mitigate perceptions of aggressive communications [58].

Homophily: Homophily is another factor that shapes social connections, which in the context of cognitive security considers diversity of information behaviors and receptiveness to new information. Degrees of homophily allow individual cognitive security to reflect and transfer within the group. The greater the homophily within a group, the more close-knit and greater the chance to become an echo chamber. Differentiating individual opinions to correctly acknowledge disinformation in groups with echo chambers can be difficult if some individuals lack the "necessary instruments and cognitive abilities to assess the level of credibility of pieces and sources of information with which they come into contact" [59]. When disinformation is accepted within groups with high homophily, it diffuses quickly through the group and bridges

to similar groups [60]. On the flipside, groups with low homophily may prevent disinformation from having wide acceptance within the group [60]. Groups with low homophily then demonstrate a greater chance for individuals within the group to intercede the disinformation and benefit from differing levels of individual cognitive security within the group. Malicious actors that produce disinformation recognize the role of homophily and confirmation bias in social connections and leverage those relationships to create more sophisticated types of antagonistic information operations [61].

Social roles and overloading: Other relationship factors include social roles and overloading behaviors. Social roles can emerge within interpersonal relationships and affect the development and transmission of cognitive security capabilities. Social exchanges, which include sharing and correcting disinformation may require use of social capital within the group. Individuals may weigh their role and value in a relationship or group as a factor whether to act on correcting others in the group based on the potential social costs [60]. In addition to social roles, the overall volume of information flowing between social connections can affect the ability to recognize disinformation. Large amounts of information, correct and incorrect, cycle through various communication platforms and parse through groups. The degree to which the amount and type of information presented within a social circle, particularly within a content delivery system, can overload individuals [62]. Thus, while an overloaded individual could benefit from the cognitive security of others within the group for information group members share, they would also rely upon those group members to identify information injected into the group by content delivery systems.

3.3. Organizations

An organization is a group of people with a common purpose: this includes government departments, businesses (e.g., companies, social media platforms), nonprofits (e.g., United Nations agencies etc), topic-specific facilities (e.g., hospitals, health facilities, etc), and informal groups (e.g., cognitive security monitoring and response groups: fact-checking, election monitoring) [63]. It also includes the groups and businesses that support the creation, dissemination, and use of mis- and dis-information.

Organizations' role in cognitive security: Organizations might maintain their own cognitive security, or be part of the cognitive security of the vertical (e.g., elections, health, transport) system. Organizations also affect the cognitive security of individuals, communities, and other stakeholders, including the end-users that they serve.

Organizational influence: Organizations influence cognitive security through narrative- and activity-based mitigations and counters to misinformation and other cyber harms. Narrative-based counters include prebunking, debunking, and making clear information available in the spaces where individuals seek, post, and share both information and misinformation. Activity-based mitigation and counters include reducing the visibility of online misinformation content, sites, and creators, and training influencers in areas where misinformation has spread offline, in local languages, or to communities that are hard to reach with broader online campaigns.

Boundary issues: Organizations implementing cognitive security for themselves have a boundary problem. Unlike other areas of security, the organization needs to monitor and act on not just its own systems, but also on systems, e.g., social media platforms, controlled by other

bodies. This forces organizations to cooperate on cognitive security mitigation and counters. Organizations control the information that they produce, their own responses to external content, and cooperation with other bodies. Larger organizations have communications and marketing departments that scan media, such as social media, traditional media, and trade publications, for mentions of the organization and subjects that affect it, respond to, and produce information and media about the organization. Few organizations are scanning for misinformation that affects them; fewer still (outside media and social media organizations) scan for misinformation about their vertical, or affecting their stakeholder populations.

Factors in organizational cognitive security: Factors that affect organizations' own cognitive security include the organization's access to information monitoring and response resources (which is often related to organization size), access to collaboration resources (e.g., with other organizations, and communities in its area), and visibility of subcommunities within or overlapping the organization. For example, health organizations often contain medical staff who are part of their own information communities. Organization structure can create issues for which the solutions are not always clear, such as acknowledging who is responsible for cognitive security. The dynamics of an organization's social power also affect its cognitive security: external perceptions (e.g., stigma) and accessibility both of the group and by the group to external mitigation and response resources that it needs. Like individuals, organizational characteristics can make cognitive security for the organization and its people easier or harder to obtain.

The importance of plans: An important first step in implementing cognitive security with organizations is to create a cognitive security plan, detailing potential and allowed responses to a disinformation incident, steps in those plans, with contacts listed for internal and external collaboration (e.g., image production, social media contacts), and mitigation steps that could be taken to reduce the potential spread and effect of future events (e.g., creating and amplifying narratives in information voids).

3.4. Communities

A community is a group of people who may or may not be spatially connected and could be local, national or international, but who share common interests, concerns, or identities. Factors that affect community cognitive security include the community structure (e.g. community cohesion), trust levels, existing shared beliefs, and the challenges specific to that community, including communications challenges. Other factors include literacy, language, existing communications channels and communication skills (e.g., some communities don't understand maps, and there are similar issues with other new information types), access to information and bandwidth, and the monetary cost of access (for searching, posting, and sharing information).

Trust: Internews' work on community-based misinformation response covers several community factors [64]. Trust is key in community cognitive security incidents and defenses. Trusted community information sources include individual influencers (e.g., community leaders, and community information sources like librarians and local officials), and influential organizations (e.g., religious bodies) and meeting points (e.g., barbershops). Less-trusted information sources are generally less local, and include government organizations and websites, science, and mainstream media. Community cognitive security plans should take these different levels of trust, and their management, into account.

Existing shared beliefs: Disinformation often takes advantage of existing in-group narratives and schisms between groups. Examples include the use of Buddhist/Muslim tensions, Dinka/Nuer tensiobs in South Sudan, and community-level distrust of government fuelling polarization during COVID-19. Factors listed include political conflict, social upheaval, economic stress, and other sociological or psychological factors [65].

Response origins: Where cognitive security plans originate from is also important. Heeks described development as either pro, para, or per-poor communities, but this categorization also applied to other types of community [66]. Pro-community work occurs outside communities, but on their behalf; para-community work is done working alongside communities; and per-community work occurs within and by communities. Local context is important to cognitive security: pro-community centralized responses miss that context, e.g. that the US contains multiple Hispanic communities with different cognitive security needs, whilst grassroots per-community cognitive security originates from the community needs. This can create a disconnect between what the community thinks is appropriate intervention, and what funders and information controlling organizations think it should be, and often gives rise to discussions about who represents a community, and whose voices in it should be heard.

Online communities: Online and physical communities differ in several ways [65]. Lieberman and Schroeder identified four main differences as fewer nonverbal cues, greater anonymity, more opportunity to form new social ties and bolster weak ties, and wider dissemination of information [67]. Online disinformation takes advantage of the three "Vs" of big data: greater volume, at greater velocity, and over a wider variety of channels, languages, formats, and community structures. Anonymity allows users to spoof (pretend) membership of offline communities, increasing trust in their roles as community members or influencers. Wider dissemination of information gives access to many more communities than those bound by geography or spoken language, with automation and electronic content production making the management of multiple "sock puppet" accounts and groups feasible [68]. More opportunity to create and affect social graphs (the ability to form new ties and bolster weak ones) has been useful to the creators of misinformation-led online groups [69]. Despite this, online communities do still have geographical factors, including algorithmic containment of what they view because of their location, language, search terms, and influencers.

Finally, not all community falsehoods are bad: Community information and coherence is also sometimes based on false information in the form of myths, convenient untruths, such as backstories, and other misinformation. These can be used as signals of belonging to a community without being believed. Santa Claus dropping down chimneys is clearly a myth, but determining which false information is normal to a community and not to be countered might not be easy to determine from outside.

3.5. Policy

Public policy plays a substantial role in the governance of the flow, use, and storage of information, as well as guide actors within the information and social environments. Such policies also influence and are influenced by individual, group, and organizational culture and dynamics, creating a symbiotic system that can reinforce systems of cognitive security. Moreover, policy is one vehicle that guides how individuals navigate and interact with the institutions and other

actors in the cognitive security landscape. Policy affects several key factors which can trickle down toward the development of individual cognitive security. Such factors include areas such as legislation and executive policy, coordinated planning documents, stakeholder involvement, policy hesitancy or resistance, funding and resources, and research and reporting endeavors.

Whether individually or as a collaborative group, countries can take a proactive approach to stem the flow of disinformation to their populations. For example, the US and the European Union (EU) actively work with experts to identify and counter sources through legislation [70]. Regulation is one type of legislation and executive policy that has a forcing function on the transmission of disinformation. Regulation in the US requires advertisers to track, sometimes publicly, who purchased ads and for much in an effort to improve election transparency [71, 70]. At a subnational level, the US states of Washington and California introduced policy to improve media literacy in schools [72, 73]. Separate similar policies from different groups, such as intergovernmental or across sectors, can form overlapping mosaics that enhance or hinder cognitive security against botnets and offset disinformation. These policy mosaics are program laboratories that produce vital knowledge developments. Yet, policy mosaics can also result in the creation of a fractured field of consent management platforms for data protection, where platforms and use of data vary in response to each privacy policy directives [74, 75]. Governments can also use policy planning documents, such as strategic security plans, to help set agendas, as well as establish leadership and security topic importance. The Biden Administration's recent updates to the United States National AI Initiative through AI.gov present strategic pillars like education and training to increase and improve the workforce pipeline and emphasize the importance of incorporating socio-technical perspectives [76].

The stakeholders involved in policy development and implementation have direct and downstream impacts on the type, quality, and quantity of policies that affect cognitive security and disinformation through their formal and informal policy institutions and networks. The number and type of stakeholders across organizations to be involved in public and other macro-level policies vary by purpose, while Maynard and colleagues identified nine groups of stakeholders that should be involved information security processes within an organization: executive management, ICT specialists, security specialists, legal and regulatory, business unit representatives, the user community, human resources, public relations, and external representatives [77]. Moreover, stakeholders should remain involved throughout information security life cycles [78, 79]. Whether within or across stakeholder organizations, each participant and group bring their own context regarding what matters. Kshetri found the contexts of formal and informal institutions and their institutional changes to be informative toward the networks formed and relationship dynamics, which in-turn impacted cloud technology and its security development [80]. As cognitive security would encompass use of cloud systems, the contextual drivers and premise may also be applicable more broadly to cognitive security and resilience.

The private sector may hesitate or resist policy if there is perceived overreach, censorship, or a lack of limits and boundaries. Technology remains politically contentious. Examples of national security policy resistance include allowances of data collection and use, disclosure mandates, costs to small businesses, unclear liabilities, information sharing that becomes adversarial roadmaps, and failure to use pre-existing legislation [81]. Reevaluating policy through other lenses and being interdisciplinary are two avenues to help mitigate policy resistance and align matters of importance, particularly for wicked problems like disinformation. Cognitive

science-based approaches serve as a lens to better understand the ethics and policy implications of issues such as AI and botnet mitigation [82]. Funding, timing, and resource allocation are central elements of policy which are also determined by involved stakeholders, and may influence policy resistance. Funding, timing, and resources also serve as signals which affect communities, organizations, and individuals working on cognitive security and resilience topics. Resource allocation also reflects decision-making priorities and shapes the environment for future cognitive security efforts. In their work at the National Institute of Standards and Technology (NIST) advising government executives, Bowen, Chew, and Hash identified capital planning as an essential element alongside awareness and training as part of information security program development [83].

Policies mandates and support for research and reporting endeavors are additional types of barriers or accelerants for innovation and accountability. The US federal government's 2020 National Defense Authorization Act (NDAA) honed in on the relationships between social media platforms and information operations. In response to the NDAA and other rising disinformation concerns, new organizations, like the Cognitive Security Intelligence Center and National Commission for Countering Influence Operations (NCCIO), emerged together to harness academic, civil society, industry talents to defend against online disinformation [84]. Inadequately funded organizations, such as university labs and private companies, may not be able to fully participate equally with other peer stakeholders. On the flipside, research organizations with their reputations on the line may engage less if participation brings unwanted adversarial attention, such as from botnets [82].

Yet, for all that policy can do for cognitive security, more policy-related questions arise that may continue to sway security discussions. This is due to the inherently complex and emergent nature of the socio-technical challenges that these policies are trying to address. As policies attempt to eliminate disinformation and reduce its impact, those policy solutions will continue to raise perceptual, economic, sectoral, ideological, ethical, and legal questions [85]. Many of these are carried out at the society level.

3.6. Society

A variety of societal characteristics have been shown to influence cognitive security and resilience. This level encompasses some of the most impactful but distal determinants that are also among the most enduring and resistant to change, such as cultural values and traditions, media and social media influences, economic factors like poverty and inequality, and discrimination and marginalization.

Culture and ideology: A recent cross-national comparison of resilience to online disinformation found that societal polarization decreases resilience to online disinformation, likely due to increasingly disparate representations of reality that make it more difficult to distinguish between false and correct information [86]. Societies characterized by a higher degree of populism may also be more susceptible to disinformation due to the underlying worldview, which includes sentiments such as anti-elitism and mistrust of expert knowledge. The same factors that make populist societies vulnerable to information disorder also make them more susceptible to anti-vaccine appeals.

Media and free press: Weak public broadcasting services/public service media is associated

with greater susceptibility to online disinformation [86]. Similarly, societies with stronger media infrastructures and an independent and free press tend to be more resilient to disinformation, while those with higher levels of censorship tend to be more vulnerable [87]. However, societies in which news consumers are distributed across a diverse and fragmented media ecosystem may have increased susceptibility because of the greater number of entry points for both foreign and domestic disinformation [86]. Low levels of distrust in institutional sources of knowledge (such as science and medicine) and higher levels of funding for public service media are associated with greater resilience to disinformation, as is a lower degree of media polarization and fragmentation [87].

Social media: Societies with greater numbers of social media users, higher rates of social media use, and greater reliance on social media as a news source tend to be characterized by poorer knowledge of public affairs, reduced political learning, and increased susceptibility to online disinformation [86].

Economy: Economic factors such as poverty rates, unemployment, resource allocation can also make populations more vulnerable to information disorder [88]. Similarly, societies with larger advertising markets and more potential consumers tend to be more susceptible to disinformation than those with smaller advertising markets [86]. This is attributed in part to the significant amount of false content that is produced for the purpose of generating advertising revenue.

Discrimination and marginalization: Factors such as racism, discrimination, and oppression are also important determinants of cognitive security. Societies characterized by a greater degree of marginalization of minorities may be more susceptible to disinformation, in part because of associated perceptions that the political, social, and economic systems are "rigged" [89, 90].

4. Use Case

With the SEM applied to a cognitive security context, we now apply it to a use case of US-based, COVID-19 vaccine hesitancy and refusal based on disinformation and disinformation response.

4.1. Individual

At the individual level, vaccine-related mis- and disinformation can lead to vaccine hesitancy through several different pathways, many of which also represent opportunities for possible intervention and mitigation. Key mediating factors include knowledge and understanding, personal experiences, cognitive and emotional appraisals, and risk perceptions, as well as demographic and personal characteristics such as race, religion, and political ideology.

There is a well-documented pattern of racial disparities in vaccine-related beliefs and behaviors, and this has continued during the coronavirus pandemic [91]. In the US, members of racial minority communities have been specifically targeted by vaccine-related mis- and disinformation, which is believed to have contributed to increased rates of vaccine hesitancy within these communities. Given the legacy of racism in science and medicine, race may also impact factors such as trust in scientific and medical institutions, which could influence vaccine hesitancy among members of racial minority communities by driving them to seek out information from alternative sources who they trust but may not always be credible. Further discussion of the

impact of race and racism on vaccine hesitancy, and their relationship with vaccine-related misinformation, is available in the societal section.

Previous experiences with vaccination and/or knowledge of someone who suffered from a vaccine-preventable disease or an adverse event associated with vaccination are associated with vaccine hesitancy [92], as is being a parent [93]. During the COVID-19 pandemic, particularly, research has found that Americans who identify as evangelical Christians are more likely to be vaccine hesitant and less likely to respond to persuasive messaging aimed at shifting their attitudes about vaccination [94]. Political affiliation has also been shown to influence risk perceptions during the COVID-19 pandemic, with Republicans far less likely to view the virus as a major threat to public health [95]. Given that low levels of perceived risk and susceptibility are associated with a lower likelihood of vaccine uptake, this may be another avenue through which exposure to misinformation influences vaccine hesitancy [96].

Previous research shows that certain psychological factors, such as conspiratorial thinking and endorsement of conspiracy theories, disgust sensitivity, and higher levels of reactance and non-conformity are associated with negative vaccine attitudes and lower intentions to get vaccinated [97, 98]. These patterns have also been documented during the COVID-19 pandemic, with studies showing that conspiratorial beliefs are associated with negative attitudes about the COVID-19 vaccine and reduced intentions to get vaccinated [99].

Concerns about the safety of vaccines and the potential risks are two of the main drivers of both general vaccine hesitancy and, specifically, COVID-19 vaccine hesitancy [100, 101]. Exposure to vaccine-related misinformation may alter risk perceptions, resulting in negative attitudes toward vaccination and, in some cases, vaccine hesitancy [98, 102]. This may be particularly true for personal narratives about adverse events associated with vaccination, which are a very common and influential form of vaccine misinformation [103]. Cognitive biases may also contribute to vaccine hesitancy after exposure to vaccine-related mis- and disinformation [100]. For example, since mis- and disinformation tend to be more emotionally salient than accurate information, these messages may be easier to recall and lead to misperceptions about the frequency of rare events, ultimately resulting in vaccine hesitancy. Additionally, emotionally driven messaging and vaccine-related misinformation that manipulate emotions such as fear and anger have been identified as key contributors to vaccine hesitancy [104]. Exposure to COVID-19-related misinformation has been found to be associated with increased fear and stress, which in turn may impair information processing and lead to poorer health-related decision-making [105]. Studies show that psychological distress is associated with vaccine hesitancy, and there is evidence that this relationship is mediated by mistrust and belief in conspiracy theories [106]. Additionally, research indicates that people may be more likely to share low-credibility sources of COVID-19 vaccine information as they cope with anxiety, anger, and fear, suggesting that there may be a feedback loop involving exposure to emotionally-driven mis- and disinformation, emotional appraisal and response, and information behaviors, which may in turn result in increasing levels of vaccine hesitancy [107].

People who rely on Facebook as their primary source of news about COVID-19 are more likely to be vaccine hesitant than those who get their news from other sources [108]. This may be at least partially attributable to the types of information individuals are likely to encounter on Facebook, or it may be a reflection of underlying characteristics that make certain individuals more likely to seek out news content on Facebook and more likely to be skeptical of vaccination.

Either way, the association between using Facebook as a primary news source and vaccine hesitancy points to a potential avenue for targeting future vaccine communication efforts.

The majority of interventions aimed at countering or mitigating the effects of vaccine-related mis- and disinformation target individual-level factors, such as susceptibility, vaccine-related beliefs, perceptions of personal risk, or digital literacy. Research suggests that refutation messages that address the affective and cognitive evaluations of vaccine-related misinformation may help reduce vaccine hesitancy among people exposed to misinformation. Promoting vaccine uptake by addressing the motivational roots of vaccine hesitancy, such as concerns about vaccine safety and effectiveness, may be a promising strategy for countering certain vaccine-related information harms, while fact-based rebuttals focused on knowledge deficits do not appear to have much of an impact [109, 110]. During the COVID-19 pandemic, there has also been a focus on recruiting social media influencers to promote vaccine uptake, but research suggests that exposure to authoritative information about the vaccine is a stronger incentive to get vaccinated than endorsement from influencers [109]. As is the case in public health, individual-level approaches to countering information harms are limited in their potential impact, and are likely to be more effective when paired with approaches targeting higher-level factors.

4.2. Interpersonal

When it comes to individuals choosing whether to become vaccinated against COVID-19 or not, family, peers, and other social connections play an important role. These interpersonal interactions are key factors in shaping individual perceptions of what to believe or reject about the vaccine. Adolescent level doses came later than adults and the interim period was strife with a spectrum of mis- and disinformation as to whether children should receive the vaccine or in what dose [111]. Recent findings from Rogers and colleagues discovered that family, particularly parents, norms largely influenced adolescent vaccine intent; peer norms had a lesser but still significant impact [112]. Stepping back to consider all adults, surveys around May of 2021 consistently found that peer effects from advice to pressure had far more effect on vaccination decision than political preference, despite divergent political views of COVID-19 largely dividing the nation [113].

Following expectations, loose social environments such as Twitter conversations about vaccine fraud with thousands of people had high associations between low vaccination rates and negative attitudes toward the vaccine; yet, that effect disappeared among similar discussions with family and close friends [114]. Close social connections as fact checkers serve as a final defensive line against misinformation, out-performing validation from experts like Dr. Anthony Fauci [114]. We speculate that the CDC's recognition of the influence of interpersonal relationships supported the CDC creation of entire guides about how to discuss COVID-19 with friends and family [115].

Other interpersonal factors continue to yield results for vaccine uptake and overcoming disinformation. Homophily, particularly on measures of race and ethnicity, was a primary driver of becoming vaccinated and positive views about the vaccine, which follows expectations from social contagion theory [116]. Similar homophily results are found comparing COVID-19 vaccine update to other vaccines and antibiotic use [117] and socio-demographics effect on

various prophylactic measures [118]. Buttenheim's Congressional expert testimony on strategies to reduce vaccine hesitancy recommended overcoming misinformation through leveraging the social capital of well-known individuals within a community, such as stylists and barbers [119]. Lastly, the length and severity of the COVID-19 pandemic gave rise to large swaths of information, increasing the potential for individuals to experience information overload, in-turn leading to issues like mental fatigue and determining credibility through cognitive heuristics, but groups offset this through group coping practices and extend individual ability to communicate about COVID-19 [120].

4.3. Organizations

Organizations involved in US COVID-19 vaccine promotion efforts include the CDC, which together with the WHO is active in trying to counter what has been termed an "infodemic" [121, 122]. CDC's advice to communities includes using social listening on social media and traditional media channels, logging and analyzing misinformation in these channels; listening to the community to identify content gaps, perceptions, information voids, and misinformation; sharing clear, accurate information, and using trusted messengers (influencers) to boost credibility. Outputs from the CDC include regular State of Vaccine Confidence Insights reports [123].

Other organizations involved in US COVID-19 vaccine promotion efforts include state and local health departments. For example, the Massachusetts State Department of Health has a Vaccine Ambassadors scheme, making public health professionals available to community forums and meetings in 12 languages including American Sign Language [124]. However, these agencies have also faced significant challenges during the pandemic, in large part due to poor coordination and communication between local, state, and federal health agencies, particularly in the early months. Miscommunication, lack of or delayed information sharing, incompatible databases, inconsistent reporting practices, and insecure communication channels are just a few of the problems that have arisen. Similarly, efforts to develop effective vaccine communication strategies have been complicated by local and state-level variation in COVID-19 trends, which at times has resulted in confusion due to seemingly conflicting information coming from federal versus state and local health agencies. Hospitals, schools, universities, and churches are other examples of organizations involved in vaccine promotion and communication efforts.

4.4. Communities

Communities are active in vaccine disinformation creation, amplification, mitigations, and counters. Online communities have formed around antivax narratives and vaccine conspiracy theories, or been created by admins, some linked to known disinformation creators, seemingly to advance these narratives, and increase the division they create. High-profile online influencers also amplify these narratives [125].

Communities affected by vaccine misinformation include immigrant communities. In Boston, the Haitian immigrant community sees vaccine misinformation in Haitian Creole; community-based responses to this include faith leader narratives, such as Pastor Keke on platforms including local radio, and the Mattapan community health center placing local ads and flyers

[126]. Hispanic communities in the US have also been targeted with vaccine disinformation; one issue with this is the assumption of many higher-level (e.g., government level) responders that Hispanic communities in the US are a uniform population, rather than targeted separately by factors including their countries of origin: Cuban-American, Puerto-Rican, and Mexican targeted disinformation, narratives, and channels vary significantly from Cuban-American fear of leftist politics to documented histories of medical experimentation on Puerto Ricans [127].

Other communities targeted by disinformation in the US include Black communities [128] - already targeted disproportionately with election related disinformation, wellness communities, and parents of small children. Each of these communities has online groups and spaces which could be targeted by fake profiles, misinformation, and artificial amplification of vaccine misinformation. Healthcare worker communities are also targeted: Doximity, the "LinkedIn for doctors" connecting 80% of US physicians, also contains vaccine disinformation [129].

4.5. Policy

With COVID-19 at global scale, infecting nearly 300 million people and killing almost 5.5 million, it was inevitable that governments would get involved. Governments at all levels across the US activated a wide range of policies to reduce vaccine hesitancy and increase vaccine uptake. Yet, differences in policy formation and compliance varied largely by political lines. Messaging from elected officials and political elites drove narratives and vaccine endorsements, or lack thereof, which shaped early individual perceptions of the vaccine [130, 131, 132]. Despite political fractures, leadership from the top initiated efforts to reduce misinformation and disinformation, such as through science-based public health campaigns identified and supported through the US National Strategy documents [133]. Additionally, the US Department of Health and Human Services (HHS) initiated a 5-year strategic plan on vaccines, which included goals specifically toward partnership development to combat disinformation and reduce vaccine hesitancy [134]. The plan is national in orientation, yet global in scope, and covers more vaccines than COVID-19, but maintains targets and metrics at the individual level. In addition to rolling out policy to reduce disinformation and increase vaccinations, some policy was inward looking to conduct governmental self-checks. The US Cares Act set requirements for the US Government Accountability Office to perform oversight on COVID-19 related policies, including stakeholder efforts on vaccine administration and information sharing [135].

In this use case, these examples combine funding and resources considerations with research. With no end in sight, agencies across the federal government initiated research funding on disinformation and vaccine hesitancy. Even before the COVID-19 pandemic, HHS was sponsoring work to "help individuals make informed decisions about immunization for themselves and their families." [136]. Of course, the NIH are deep into supporting vaccine and decision-making research; they a wide range of grants and cover issues such as community-level interventions for vaccination uptake, evaluation of government policies or initiatives that "that mitigate or exacerbate disparities in vaccine access, uptake, and series completion", and examine barriers, access, and other measure among populations "who experience health disparities" [137]. Even NASA opened grants for access to its remote sensing and satellite data to better understand spatial effects on "environmental, economic, and/or societal impacts of the COVID-19 pandemic" and how its systems can benefit decision-making research [138].

4.6. Society

Anti-Asian sentiment and discrimination have been widely documented during the COVID-19 pandemic, in large part because the virus was first discovered in Wuhan, China, which has led to the proliferation of conspiracy theories and attributions of blame for the pandemic. This is even apparent in search terms about the pandemic, which reflect stigmatizing beliefs about the virus and its origins [139]. There is concern that these beliefs, combined with existing ethnic and racial biases, may have spilled over to the healthcare system and public health communication, resulting in culturally insensitive vaccine messaging and poorer quality interactions with healthcare providers [140, 141]. Given that trust is a key factor in determining vaccine-related attitudes and behaviors, it is possible that these negative experiences may have contributed to vaccine hesitancy among some subgroups of Asian Americans.

The history of anti-Black discrimination and racism in the U.S. healthcare system is also believed to play a significant role in driving COVID-19 vaccine hesitancy in Black communities [128]. This problem is compounded by vaccine-related misinformation targeting Black communities, which fuels mistrust and negative attitudes toward vaccination. Additionally, high levels of mistrust can increase susceptibility to misinformation [49]. Inequality-driven mistrust has been recognized as a distinct phenomenon among communities who have historically experienced disenfranchisement [142]. During the COVID-19 pandemic, this has manifested itself in false belief systems such as the idea that vaccines and therapeutics are being deliberately withheld from certain racial groups. Recognizing the significant role of racism in fueling mistrust and harmful health beliefs such as vaccine hesitancy, researchers are calling for solutions to information disorder that directly address racism [142].

Media coverage is believed to have contributed to fear, mistrust, and stress during the COVID-19 pandemic, which may have resulted in increased vaccine hesitancy [143, 144]. While clear, accurate, and timely information from trusted sources is necessary to make informed decisions during public health crises, there is a delicate balance to strike between providing too little versus too much information. On the one hand, information vacuums and infrequent updates during ongoing crises can lead to the proliferation of rumors and increased levels of uncertainty, psychological distress, and fear, but too much information may cause people to become overwhelmed, confused, and unsure of who or what to trust. Paradoxically, as reporters and news outlets tried to keep the public informed about the outbreak, excessive exposure to news stories about COVID-19 may have had a negative impact on preventive behaviors such as vaccination. This has been attributed in part to the observed impacts of information overload, which has been shown to lead to maladaptive behaviors and information avoidance during emergencies [145, 146]. Additionally, perceptions that the media exaggerated the risk of COVID-19 are associated with vaccine hesitancy, possibly due in part to disengagement with authoritative sources of information and increased engagement with "alternative" news sources [143].

At a national level, social media use and the prevalence of foreign disinformation online has been shown to be significantly associated with COVID-19 vaccine hesitancy among the population [147]. Low levels of societal trust in scientific and biomedical institutions, and low levels of citizen engagement with the scientific community, are also associated with COVID-19 vaccine hesitancy [148]. Societal norms that prioritize individual freedom over the protection

of vulnerable groups have also been identified as a significant driver of COVID-19 vaccine hesitancy [149]. This coincides with trends in anti-vaccine messaging, which in recent years have increasingly framed vaccine refusal as a civil right and vaccine mandates as a form of tyrannical government overreach [150]. Political and voting trends have been shown to be associated with COVID-19 vaccination attitudes and behaviors, such that higher percentages of votes for Donald Trump are significantly associated with lower vaccination rates and increased vaccine hesitancy [151]. Additionally, research suggests that Christian nationalism is among the strongest predictors of vaccine hesitancy, in large part because of its association with distrust of science, hostility towards authorities other than the church, and endorsement of misinformation espoused by Donald Trump [149].

4.7. Integration

While application of the SEM allows breakdown analysis of stress points and interventions of an information-based harm within each level, the levels do not operate in isolation from each other. This integration section details examples of cross-level analysis for a microchip in the vaccine misinformation scenario. October 2, 2020, Charlamagne Tha God, while on The Breakfast Club radio show claimed, "[m]illions will line up to take the vaccine, and boom, microchips for all of y'all, right in time for goddamn Thanksgiving" [152]. From there, the rumor of the vaccine injecting microchips spread rapidly. It was exacerbated and amplified by media outlets and influencers, spinning comments from Bill Gates in a Reddit Ask Me Anything conversation about digital vaccine cards into a narrative of microchipped vaccine cards as part of a larger tracking system [153, 154]. As of March 2021, two percent of surveyed individuals representing the American adult population believed the vaccine contained a microchip, but nearly 27 percent of survey respondents were unsure which together accounted for almost 75 million people [155]. In truth, neither the vaccine nor vaccine passports and certification cards contain microchips, but the microchip information-based harm is widespread [156, 154].

Despite the prevalence of the microchip rumor, there are viewable countermeasures and counter-initiatives that span the social ecological levels. Making the vaccine ingredient list publicly available is one approach to demonstrate it does not contain any microchips. The CDC provides vaccine ingredients on their website as part of the broader vaccine information packet, along with guidance as to who should or should not receive a particular vaccine, possible side effects, other safety data, and clinical trial data [157, 158]. This information is used by other agencies, such as the FDA when determining vaccine approval status (organization), but these ingredient lists also help obtain endorsement from faith-based groups (community). Moreover, ingredient transparency helped Islamic faith leaders to determine that vaccine uptake follows Sharia (Islamic) law and leadership in the The Church of Jesus Christ of Latter-day Saints to actively support vaccination and not provide religious waivers to their membership [159, 160].

Some actors transformed the injected microchip topic from misinformation to disinformation by selectively editing video interviews of prominent business leaders and news anchors to reshape a narrative that portrays the microchips as true [156]. Institutions such as the CDC [121] and FactCheck.org [161] (organizations) provide mythbusting analysis and media coverage carries this message to the public [162, 163] (society). Live conversations between public health officials, vaccine suppliers, politicians, members of the media, and the public provide another

avenue to overcome the microchip misinformation. A televised question session by the Orange County Board of Supervisors in California with their public health administrator (organization) included inquiry about injected tracking device which was quickly debunked; this engagement may boost public awareness and transparency with constituents (individuals and communities), but it was also distributed widely by NBC news for wider dissemination (society) [162].

Beyond traditional news outlets, news is increasingly consumed via social media. Younger individuals are more likely to obtain the majority of their information online [164] and well-established journalist publications reference social media sites as references [165]. Microchip and other vaccine-related rumors spread across social media platforms, and in response, tech giants like YouTube and Twitter developed COVID-19 misinformation policies that allow for removal of posts and potential account bans (organization, policy) [166, 167]. Similarly, Facebook and Instagram, following World Health Organization guidance, (organization) incorporated group administrators on their sites (community) to help control the presence of COVID-19 misinformation and ban users violating those policies (policy) [168]. Although creating and implementing social media COVID-19 misinformation policies have mixed success [169], any actions have the potential to affect how platform users create and share their content (interpersonal), as well as engage with influencers, celebrities, public officials, and other users (communities).

At a more local and personal level, there are intervention efforts to help individuals overcome COVID-19 information-based harms, including injectable microchipping. School educators have professional training available (organization) to help "leaders, teachers and parents to become "vaccine ambassadors" to communicate better with parents," (interpersonal) including how to diffuse misconceptions about microchips without being dismissive [170]. Local investigative reporters, like Mahsa Saeidi in Tampa, Florida with WFLA news (society), connect interviews with concerned parents with a physician (community) to address the injected microchip falsehood and other fact versus fiction [171]. Other groups skeptical of the government include communities of color, young people, and the LGBTQ+ community. Recognizing this gap, the Biden administration brought together Dr. Anthony Fauci and teen social media influencers (community); those influencers then reached out to their millions of followers (society) to help dispel microchip and other misinformation while also reducing vaccine hesitancy [172]. The influencers bridged Gen-Z, Black, Spanish-speaking, LGBTQ+ communities. Moreover, influencer outreach carried into conversations between parents and their youth followers [172].

5. Discussion and Conclusion

Vaccination related information-based harms continue to pervade while the COVID-19 pandemic continues to affect individuals and societies around the world. The web of falsehoods creates and reinforces vaccination hesitancy. The SEM, adapted from Broffenbrenner, offers a holistic approach to understand information behaviors across a layered spectrum from the individual through society. Our SEM analysis extended previous information disorder and COVID-19 related research to identify contributing factors and complex relationships to vaccine uptake. Through our SEM factors, practitioners can develop interventions that span interdependent relationships for greater efficacy. Academics may leverage this adaptation of the SEM to link

research across traditional disciplinary boundaries and encourage future work on the causal relationships within COVID-19 information behaviors.

The SEM can be used to classify cognitive security, at the individual, interpersonal, community, organizational, policy, and societal levels. It should be useful for researchers and responders assessing the coverage of responses, the implications of actions, and barriers that could diminish the effectiveness of interventions at each SEM level. Expanding analysis to include not just the individual, but also the effect of family and friends, communities, etc., and considering the interactions between SEM levels, potentially increases the reach and scalability of cognitive security.

Our usage of the SEM here relies upon a heavily qualitative approach as part of our effort to establish its foundation within this information science space. The lack of quantified elements within this SEM may give some readers pause. However, we believe that lack of quantitative aspects within the SEM we present does not make it any less relevant for quantitative research. Other scholars tied areas in which the SEM can or could work alongside quantitative methods. Onwuegbuzie, Collins, and Frels [173] posited that the levels within Brofenbrenner's SEM [5] are useful for both qualitative and quantitative research. Moreover, the SEM as a framework aids the pursuit of generalization, often a focus of quantitative research, by helping scope empirical methods and designs, such as sampling frames, appropriate to one or more of the model's levels [173].

Our paper offers a novel adaptation of the social ecological model for a cognitive security context which leans heavily on qualitative description to provide a first-step foundation upon which future research, including quantitative approaches, may identify measurable variables within each level. One example of this quantitative use within another context assessed political violence and child adjustment in Northern Ireland with individual (individual level) and family (interpersonal level) demographic data, social and economic measures from the local political and religious communities (community level), as well as education system and attainment values, sectarian segregation, and policy (all society level) [174]. The political violence study then used the variables associated with the model to derive index scales and conduct exploratory factor analysis, correlations, and path analysis, also known as structural equation modeling in other disciplines. Regression coefficients and $\mathbb{R}^2$ values from the path analysis then mapped back to the social ecological model levels, illustrating potential relationships for variables within and between the levels [174]. A second example used the levels a social ecological model to frame interrelated, multi-level, quantifiable characteristics to understand alcohol use behaviors; their statistical approaches included logistic multilevel random effects models and censored regression (TOBIT) random effects models [175]. Related, the social ecological model can be used to establish the environment in which computational approaches such as nested network analysis or agent-based models operate. The levels within a social ecological model naturally lend themselves to multi-level modeling. Brown and colleagues discussed the benefits of using computational approaches to explore human-computer interactions situated in complex social environments within an HIV prevention context [176]. Of the different computational perspectives mentioned, they included the development of an agent-based model that fit within a simplified version of the social ecological model with interactions and strategies based on the environment's information landscapes [176]. Saha and colleagues took a different approach to using the social ecological model. Their work focused on using machine learning

models to help impute missing data, but the authors relied upon a social ecological model for theoretical foundation to better understand the context of their data and the environment in which that data originates and interrelates. In-turn, they believed opportunity exists to use their imputation modeling to improve upon and discover new dimensions of intersection within a social ecological model [176]. Future use of our model could leverage similar variable identification or modeling perspectives to enhance a quantitatively oriented research design, or used in a mixed-methods design to improve triangulation.

The SEM provides a novel framework for conceptualizing cognitive security, but there are limitations to its use. The primary limitation is a corollary of its strength: The SEM is broad in scope and is meant to be a comprehensive framework to guide needs assessment, evaluation, surveillance, and more, but its broad scope comes at the cost of some degree of precision. Related, the scope of the model also makes it difficult to quantify in a single measure. In previous uses, efforts to quantify the model have been carried out by using validated measures for factors at each level of the model, rather than in one comprehensive measure. There have also been successful efforts to validate hypotheses based on factors included in the SEM by using path analysis to test various models of the relationship(s) between predictor variables at multiple levels, and between those variables and a specified behavioral outcome [177]. This can be further systematized by using SEM to guide meta-analysis and systematic reviews to develop empirically grounded and testable lists of factors at each level. Integrating the SEM with other novel approaches like agent-based modeling is another promising approach to harnessing the breadth and qualitative nature of the SEM. As Rounsevell and colleagues explicated, an "ABM may include quantitative, equation-based approaches, but the rules that characterize this approach are qualitative" [178].

Questions of generalizability arise given the challenges associated with measuring the SEM. On the issue of generalizability, the findings from the current study would not be expected to be applicable to other subject matter issues, though the model and its underlying assumptions and relationships should be expected to remain stable across many different settings. Although this is a limitation, it is an inherent characteristic of research exploring the dynamic human-computer-information nexus. As Antill articulated, "By the very act of installing an information system, one is changing the situation into which it is installed [179]. Therefore, no particular 'experiment' can be repeated." Of course, this does not mean that repeatability is null and void. Rather, it means that a widely-held notion of repeatability — that the same results should be produced by any researcher in any laboratory anywhere in the world — may need to be reconceptualized to consider other forms of repeatability, such as the ability to demonstrate that the same set of variables or assumptions, held to be controlled and identical, do indeed hold up in multiple tests of the model. Similarly, there are different mechanisms of achieving validity in qualitative research. Among the most important is face validity, which simply conveys whether the results were viewed as credible, recognizable, and trustworthy by others. This is one of the primary mechanisms of transferability in qualitative research — rather than using statistical inference based on a defined population, qualitative analysis seeks to produce results, assumptions, relationships, and models that can be generalized to many settings [180].

The SEM adaptation in this paper is early-stage work and we applied it to a single use-case falsehood on microchips injected with the vaccine. Future efforts could explore additional factors within each level of the SEM and reinforce the interdependencies between levels. Next

steps to improve the model validity would implement this SEM approach for other COVID-19 information disorder use-cases. Another interesting application would be looking at algorithms (e.g., social media recommendation algorithms) through the SEM for cognitive security lens, where the neighbors of individual algorithms would be models and model instantiations sharing training datasets and results, and communities could form around the pre-trained models used in e.g., text and image understanding, with model poisoning and other machine information harms being shared across those communities and so on. Another future pathway extends this SEM adaptation as a theoretical contribution alongside to other prominent theories of information behavior within an environment, such as Chatman's small worlds micro view [181], Habermas' lifeworld theory macro view [182], the multilevel view from Jaeger and Burnett's Information Worlds [183]. Additionally, other information behavior theories could help evolve this SEM adaptation, such as Lee and Butler's theory of local information landscapes [184] to consider the materiality of information within the environment as a capacity-based construct, directionality of information seeking through Sonnenwald's information horizons information [185], or chance discovery via Williamson's incidental information acquisition [186] (1998) or Agarwal's information serendipity [187].

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